In situ Roughness Monitoring Method Using Fiber Optic Vibration Sensors

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ABSTRACT

Main purpose of pavement of the highway is to provide the safe and efficient surface of the road to the vehicles. In order to achieve the safe and efficient surface of the road, overall investigations after construction and every year inspection are performed. For maintenance of the pavement, inspections with 7.6 profilermeter or ARAN(Automatic Road Analyzer) are used, but they are not suitable for local in situ monitoring of the roughness of pavement while they are widely used for long range roughness of pavement.Therefore in this research, as in situ monitoring of roughness of pavement, we propose the vibration monitoring method using fiber optic sensors.

1. INTRODUCTION

For smart highway, continuous monitoring of pavement performance is very important. Main purpose of pavement of the highway is to provide the safe and efficient surface of the road to the vehicles. In order to achieve the safe and efficient surface of the usual highway, overall investigations after construction and every year inspection are performed. But smart highway needs continuous monitoring not just periodical inspection.

For maintenance of the pavement, inspections with 7.6 profilermeter or ARAN(Automatic Road Analyzer) are used, but they are not suitable for local in situ monitoring of the roughness of pavement while they are widely used for long range roughness of pavement. But the monitoring system of smart highway needs long term roughness measurement of pavement structure, we propose the vibration monitoring method using fiber optic sensors.

On the point of situation, which needs a technological system to estimate the status of

the structure with higher accuracy and confidence, fiber optic sensor system, which is incorrosible semi-permanent, no influence by electromagnetic waves, and able to multiplex, will be expect to take an important part to assess the safety and residual estimate the life span of the highway pavement structure.

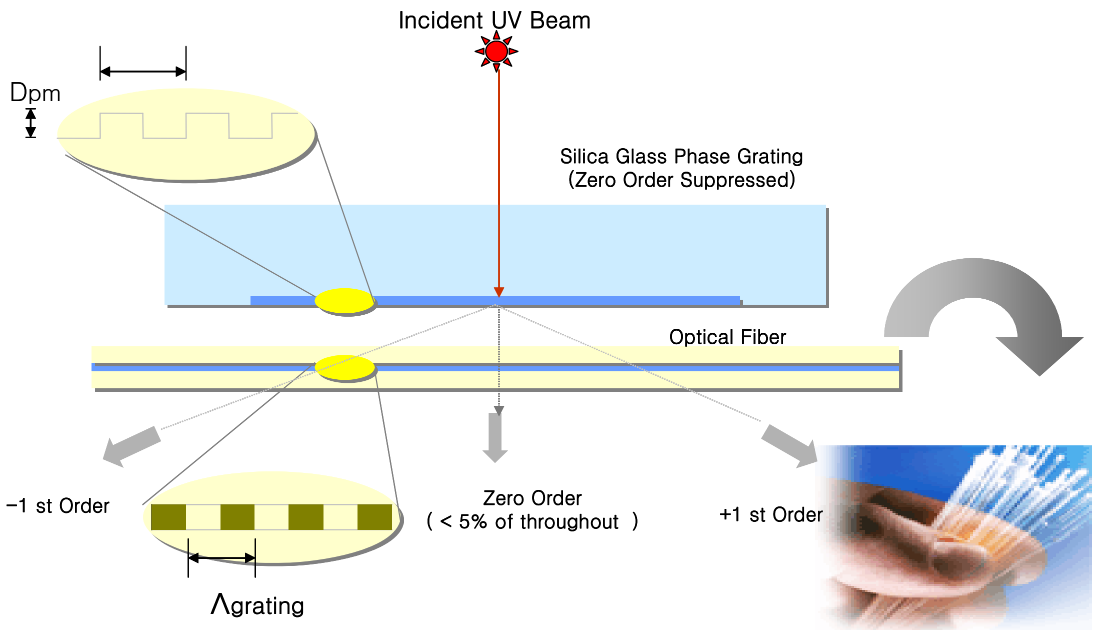
2. CHARACTER AND OPERATION PRINCIPLE OF FIBER OPTIC GRATING

2.1 Character of Fiber Optic Grating

Fiber Bragg grating(FBG) sensors, placing several fiber optic Bragg gratings as a certain length in one line of fiber, which use the change of the wavelength of light reflected from each gratings with temperature or strain change, has used more than 70% of fiber optic sensor applications.

On the core of the fiber instead of cladding, germanium is normally added to make the refractive index higher, however, a structural fault could occur on the process of the silica glass. In this case, when exposing strong ultraviolet ray on the core of the fiber optic, the bond-structure of germanium transforms and the refractive index changes. Fiber optic grating sensor use this symptom and repeatedly changing the refractive index of the core of fiber optic.

There are many ways to manufacture FBGs, however, using Excimer laser ultraviolet ray beam is the most popular way, such as <Figure 1>.



<Figure 1> Manufacturing method of FBG sensor use ultraviolet-rays laser

2.2 Principle of Fiber Optic Grating Sensor

Several gratings are used inside one line of fiber optic as a therefore, making each reflected wavelength change of the gratings, it is easy to distinguish the physical properties that a specific grating has the specific reflected spectrum of light. We call this process as Wavelength Division Multiplication (WDM). With this process, the number of the grating which could be measured in one time is limited because of the limited line-width of the source of light. Generally, about 10 gratings are used in one fiber.

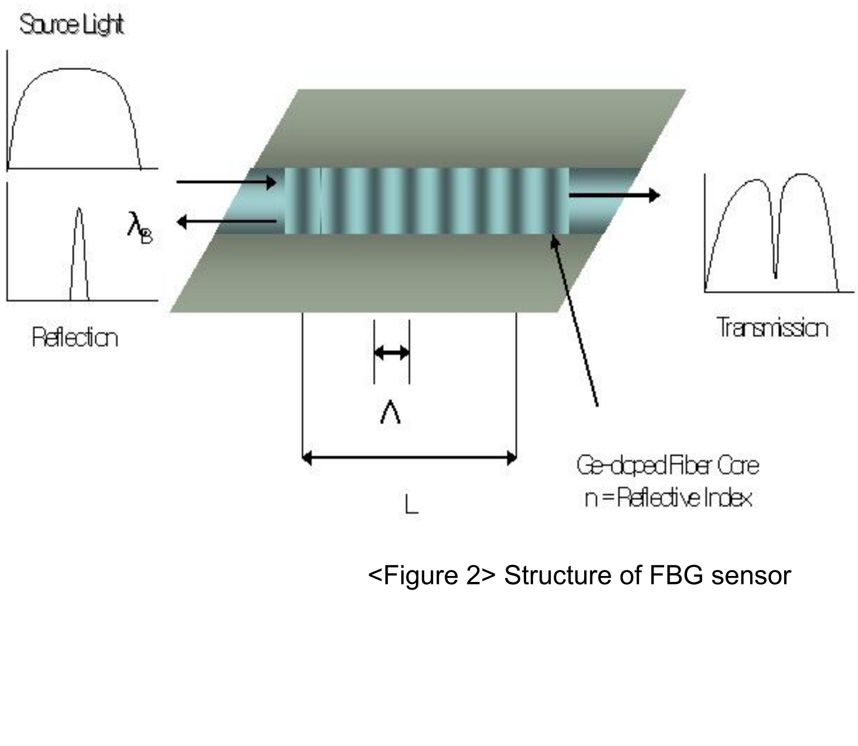
One of the biggest applications of Bragg grating sensor array, including the railway structure, is the smart structure, which could diagnose the status of the structure. Building railways, bridges, dams and other construction, fiber optic grating array can be embedded inside the concrete, and it is able to diagnose the safety of the structure by detecting strain of the interior of the structure. It is also being applied on diagnosing the wing of flying machines, such as air planes or helicopters.

As shown in <Figure 2>, reflecting Bragg wavelength is a function of effective refractive index and grating distance such as formula (1), and when the physical properties such as temperature or stress of the fiber optic grating sensor are permitted, the Bragg wavelength become different. Therefore, if you measure the change of the Bragg wavelength, it will be able to get the approval physical property on the fiber optic grating sensor.

First, the change($\Delta\lambda_B$) of Bragg center wavelength (λ_B) about strain (ϵ) change could be written as formula (1).

$$\Delta\lambda_B = \lambda_B (1 - P_e) \epsilon \quad (1)$$

P_e is Photo-elastic Constant, and on the case of Germano- silicate glass, it has approximately the number of 0.22. $\epsilon$is the strain given on fiber optic grating.



<Figure 2> Structure of FBG sensor

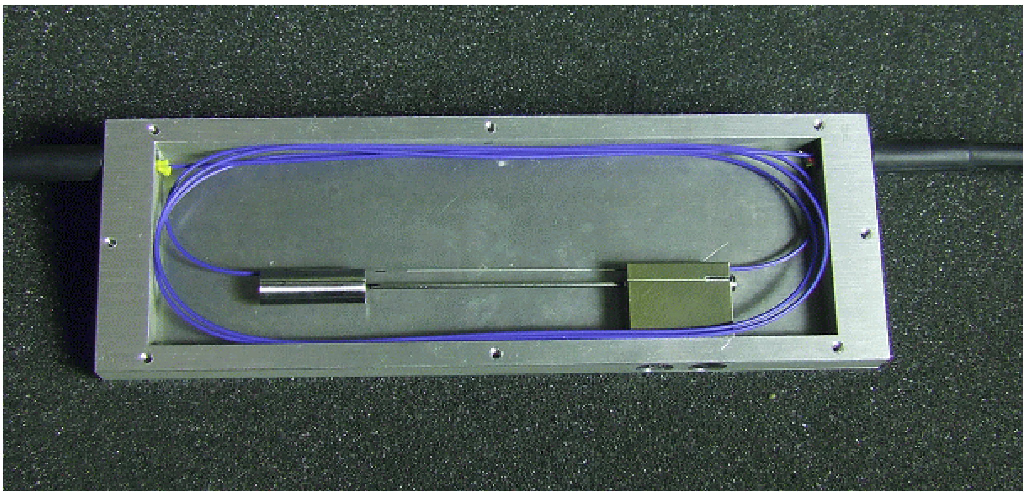
After investigating the point of fiber optic and showing that it is possible to carve the Bragg grating which reflects a certain wavelength on a specific part of the fiber optic, the research of fiber optic sensor had achieve a great development. By the reports, with no lowering of the strength of fiber optic, 12nm scale of tuning on Bragg wavelength could happen by only 1% strain. About 32nm of wavelength tuning happened by compressive force, moreover, 1.1nm of wavelength tuning happened by about 100℃ change of temperature. For an instance, to move exactly 0.01nm of Bragg wavelength, each strain and resolution of temperature has to be approximately 8×10^{-6} ε, 0.9℃, and by using equipment with high resolution, measurement of smaller movement of Bragg wavelength can be achieved.

These movements of wavelength could be observed by optical filters formed as other fiber optic gratings and fiber optic Fabry-Perot resonator, and non-symmetric Mach-Zehnder interferometer, and also could compose strain measuring equipment not related with change of temperature with simple tools. Moreover, it is simple to extend as a multi-point sensor. It could be used as a preventing system of bridges and constructions, and it is successfully examined as a diagnosis for a multi-purpose structure or a sound sensor array.

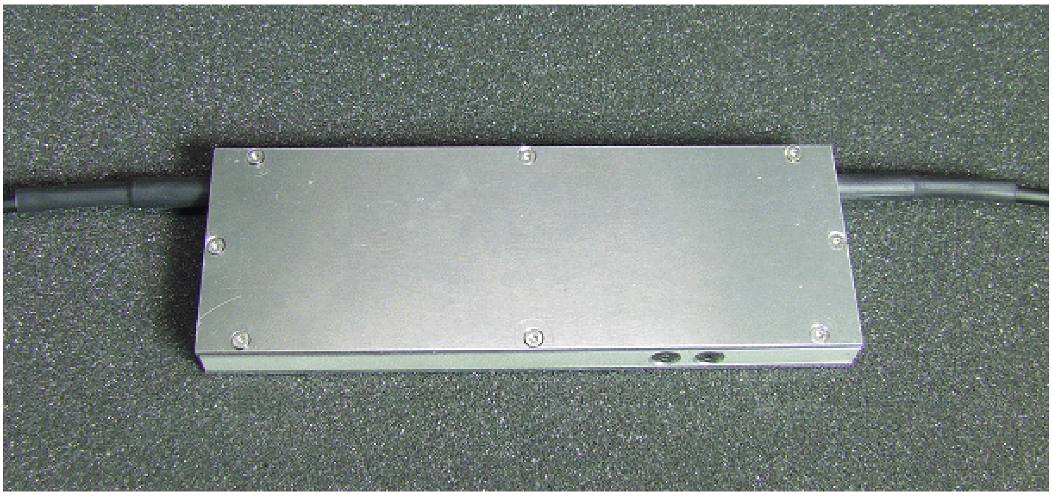
3. PROTOTYPE OF FIBER OPTIC VIBRATION SENSOR PACKAGE

In order to apply the vibration sensor to the highway, the package should be thin. Only the thin package can be embedded using saw cut strip line in the pavement. To minimize the damage which is generated by application of the sensor packages, we have to make the sensor thinner than saw cut width or we have to broaden the saw cut width more than the package thickness.

In this research, we tried to make the prototype as thin as possible. The fiber optic vibration sensor package prototype we made is shown in the <Figure 3> and the dimension of the prototype is 80mm x 50mm x 10mm.



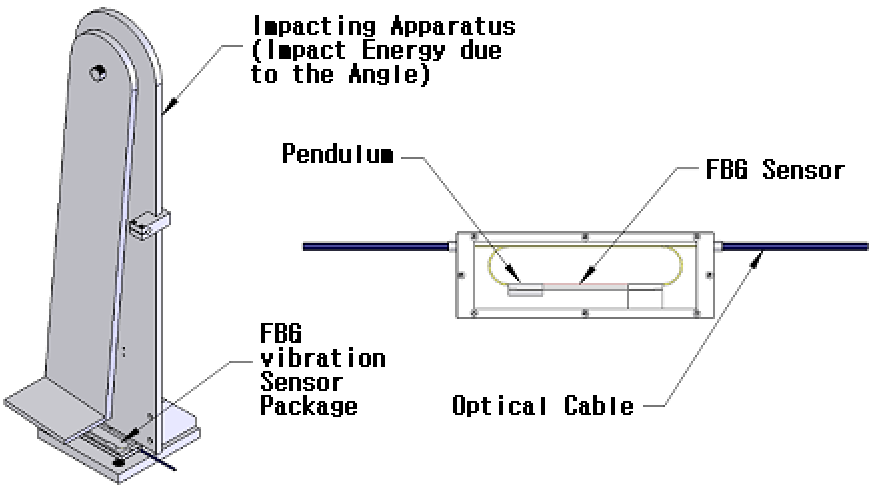
<Figure 3> Inner structure of the proto type fiber optic vibration sensor



<Figure 4> Outer shape of the proto type fiber optic vibration sensor

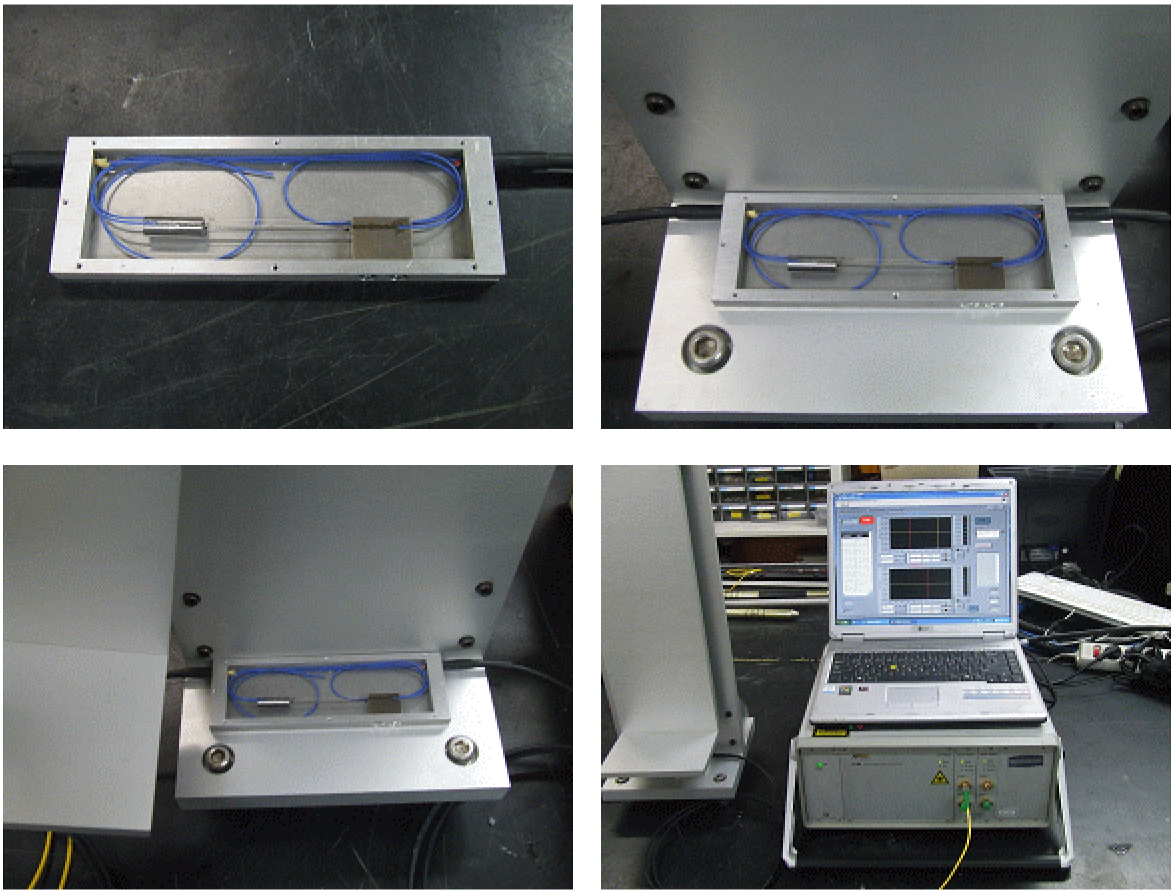
4. LABORATORY IMPACT TEST OF THE FIBER OPTIC PROTOTYPE SENSOR

For the test of the prototype, we made the impact application machine as shown in <Figure 5>. The machine has a big swing which can impact the main body. The angle of the swing gives the energy to impact. The higher the angle of the swing is, the bigger the energy of the impact. The angle varies from 1 to 5°.



<Figure 5> the pendulum type impact machine and fiber optic vibration sensor

The actual shapes of fiber fiber optic vibration sensor and the pendulum type impact machine are shown in <Figure 5> and the laboratory experiment for impact is shown in <Figure 6>.

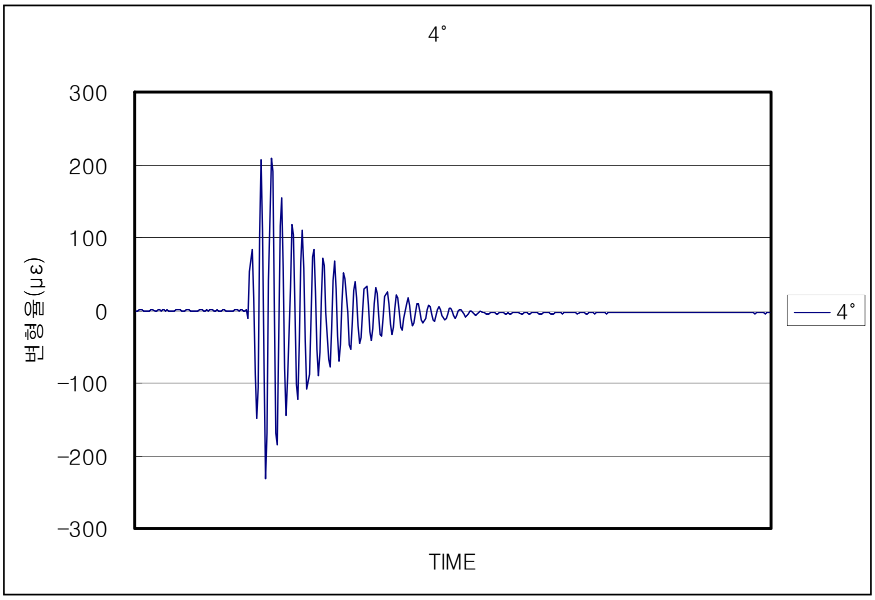


<Figure 6> the pendulum type impact machine, fiber optic vibration sensor and the system

<Figure 7> the impact test of the fiber optic vibration sensor and vibration shape in the screen

4.1 Experimental results and the data

We had several experiments with the impact machine. The angle of the swing in the machine varied from 1 to 5° to test various impact energies. One of the real data from the impact test is shown in <Figure 8>.

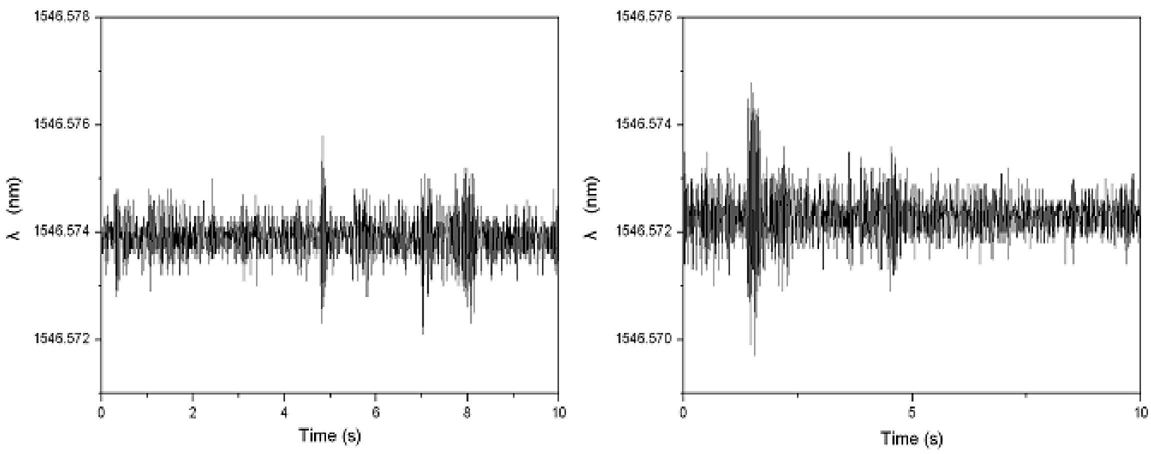


<Figure 8> Vibration shape of the fiber optic vibration sensor by the impact test

As shown in <Figure 8>, the data shows ordinary vibration by the impact and nice damping pattern.

5. ACTUAL ROAD TEST

After laboratory impact test, we tried actual road test with the prototype vibration sensor. We intended to monitor the ambient vibration by the vehicles, but the usual road showed just noises. We tried to find the road which has a step. After all, we found the road which has small step near Hongik University in Jochiwon and we install the vibration sensors to the curbs. The data showed the vibration due to vehicle very clearly as shown in <Figure 9>.



<Figure 9> Vibration data from the fiber optic vibration sensor in the road test

6. CONCLUSIONS

We designed and produced prototype fiber optic vibration sensor packages. We had a laboratory impact test with the sensors. The sensors showed very good responsibility to the impact and nice damping shape like other ordinary accelerometers. We also tried actual road test with the prototype vibration sensor. The ambient vibration by the vehicles was used for the experiment. We found the road which had small steps near Hongik University in Jochiwon. We install the prototype fiber optic vibration sensors to the curbs in the road. The data from the vibration sensor showed the good vibration patterns and the damping shape when the vehicles passed by the road..

REFERENCES

1. B. Chen, E. G. Nawy, "Structural Behavior Evaluation of High-Strength Concrete Beam Reinforced with Prestressed Prisms Using Fiber Optic Sensors" ACI Structural Journal Nov-Dec pp 708-715, 1994
2. R. M. Measures, "Fiber optic sensor considerations and de-velopments for smart structures" Proc. SPIE, Vol. 1588, pp. 282, 1991.
3. Sarah E. Mouring & Oscar Barton, Naval Academy, D.Kevin Simmons “External Retrofit of R/C Beams using Car-bon Fiber Reinforced Polymer Laminates” Stanford Univ, USA. Structural Faults & Repair conference, 2001
4. Kim, K. S., A. Segall and G. S. Springer, "The Use of Strain Measurements for Detecting Delarminations in Composite Laminates", Composite Structures Vol. 23, pp 75-84, 1993.
5. Kim, K. S., Y. Ismail and G. S. Springer, "Measurement of Strain and Temperature with Embedded Intrinsic Fabry-Perot Optical Fiber Sensors", J. of Composite Mate-rials Vol. 27, pp 1663-1667, 1993.
6. Kim, K. S., L. Kollar and G. S. Springer, "A Model of Em-bedded Fiber Optic Fabry-Perot Temperature and Strain Sensors" J. of Composite Materials Vol. 27, pp 1618-1662, 1993